

THE WORLD OF CHEMISTRY

Program #2

COLOR

Producer John Ketcham

Air Script: October 31, 1988

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Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: Earth from
space, waterfall, jungle,
desert, parrots, butterflies,
kite flying, fabrics, city
scenes, chemists working
in lab

NARRATOR (MUSIC and NAT
SOUND under):

The Earth is a colorful planet, whether
it's seen from the depths of space, or the
depths of canyons, from the lush green
of the tropical jungles to the subtle
yellows and oranges of the deserts. We
can look at our own development in
many ways; music, art, ideas,
technology, even color, because our use
of color has played an intriguing role in
advancing civilization. Much of the
world we have created for ourselves
came from our pursuit of the chemistry
of color.

SUPER: COLOR

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in flower field

ROALD HOFFMANN (SYNC):

Try to imagine a black and white world. It's nearly impossible to do so. Color is such an essential part of nature. It's there in a steady background of the living green, or the blue sky, or in the highlight of flowers or of birds. The complex brain which distinguishes humans, still depends on the senses. So it's no surprise that that feature of the visible world which gives it variety, namely color, should have entered our souls. We want color, and that's why we've brought together the plants in this garden. We describe our emotions in the red of anger, in the blues. We want color on our walls. I want it in my clothing. But what is color, and how do we get it? Well, the colors of this world depend on its components, and those are molecules, incredibly large numbers of tiny particles. In the next half-hour, we will show you how the search for new colors led to the age of modern chemistry and how color, in turn, helps us understand the properties of the world of molecules.

Chinese dragon, auto plant

NARRATOR (MUSIC under):
People and color. The relationship is strong. Today our world is rich with color.

MONTAGE of color

MUSIC UP

Tribal ceremony

NARRATOR (NAT SOUND under):
But it wasn't always that way. In their search for color, tribal people turned to roots and berries, insects and sea shells, to the earth itself. Humans have been interested in color from the very beginning. Amazingly, it took until the middle of the 17th Century to discover what color was and where it came from.

Archival drawing of
Sir Isaac Newton

NARRATOR:
Isaac Newton, in the late 1660s, demonstrated that white light was composed of a mixture of lights of different colors.

GRAPHIC: Wavelength

NARRATOR (MUSIC under):

He did it with prisms. Prisms break white light into its component colors. But why are there colors? What makes red different than violet? Light travels in waves, and each color has its own wavelength. Let's look at red. Here is the wave. The distance from the tops of these waves is called the wavelength. Now let's look at violet. The wavelength of violet is shorter than that of red. It's because light has different wavelengths that there are different colors.

· Persian carpet making, archival paintings of European royalty, colonial settlers at work

NARRATOR (MUSIC under):

Until the 19th Century, the colors of the rainbow weren't available to everyone. The blue indigo and red madder root, dyes used to color these Persian carpets, were derived from agricultural crops grown on plantations in India and Turkey. The supply of these dyes depended, in part, on the weather. The process of coloring yarn was not simple. Nor was weaving the carpets. Colorful rugs like these were expensive. The same was true of clothing. (cont.)

NARRATOR cont:

Colorful fashions and carpets could be enjoyed by the wealthy, by kings and queens. Ordinary people had to settle for much less. Science historian John K. Smith, of Lehigh University.

INTERVIEW: John K. Smith,
science historian, Lehigh
University

JOHN K. SMITH (SYNC):

Plain people, middle-of-the-road,
average people, did not wear bright
colors. It was for the rich.

Colonial weaver, archival
textile factory shots and
coal use

NARRATOR (MUSIC and NAT
SOUND under):

But there was something happening in Europe that would change all that. Machines. Mass production of textiles, of cloth and clothing, created fashion-conscious consumers. Mass production of clothing meant boom times for dye makers. But that was about to change, too. Coal was the fuel of the new industrial age. It ran the mills, and when distilled, lit the streets of Europe. What was left behind as waste was coal tar.

INTERVIEW: John K.
Smith cont.

JOHN K. SMITH (SYNC):

One of the things that you had left over
was a goo, a thick, viscous stuff, which
had no value.

Coal tar reaction

NARRATOR (NAT SOUND under):

Chemists became interested in coal tar.
Cheap and plentiful, it contained
hundreds of unknown compounds. What
was in this coal tar? Early on, benzene
and more complex compounds were
found to be in coal tar. Aniline was one
of the derivatives.

Archival photograph of
Perkin, reenactment of
Perkin's experiment

NARRATOR (NAT SOUND under):

Then, in 1856, an 18-year-old chemistry
student named William Henry Perkin
was in his laboratory at home,
experimenting with coal tar. Malaria
was threatening British colonies, and he
was trying to synthesize the known
treatment, quinine. He thought he could
make it from coal tar.

INTERVIEW: John K.
Smith cont.

JOHN K. SMITH (SYNC):

So young Perkin was going to do a patriotic act and do some good chemistry in the process. Well, his first couple of reactions that he tried yielded nothing but brown gunk, nothing like quinine. And this is where I think, again, in all these cases is the key step. He just didn't say, "Okay, next problem." He said, "Gee, brown gunk's pretty interesting. What's going on here?"

DS in lab

NARRATOR:

Series demonstrator, Don Showalter, recreates Perkin's experiment.

DON SHOWALTER (SYNC):

At 18, William Henry Perkin was already a dedicated chemist. School was out on Easter break, but he was in his basement, at home, trying to make a cure for malaria. He thought that if he combined these white crystals of aniline sulfate with these orange crystals of potassium dichromate, that he would make quinine. Now here's the way he did it. He took some of the aniline sulfate, put it into a flask of water. That ought to be about enough. And then he added some of the potassium dichromate. (cont.)

NARRATOR cont:

And he mixed it, and then heated it in a warm bath. This is the old hot water bath. He got a reaction, but it wasn't the reaction he was looking for. Instead of quinine, he got this black precipitate that came out of it. He knew that it wasn't quinine, but instead of stopping there, he was curious about this black material, and wondered what it would look like. So he filtered it. We'll pour it through the filter paper. Look at this black gunk

Reenactment of Perkin's
experiment, archival painting
of women in colonial dress

NARRATOR:

When Perkin dissolved the gunk in alcohol, he noticed the solution had a deep, rich purple color. He was about to make history. Perkin had made a synthetic dye, and it would be all the rage in Paris.

INTERVIEW: John K.
Smith cont.

JOHN K. SMITH (SYNC):

At about the time that he was doing his experiments with his purple dye, which the French called "mauve," the fashion people had already decreed that purple was going to be the color, it was the trendy color of the time.

GRAPHIC: Molecular
structure of mauve

NARRATOR (MUSIC under):

What was so special about mauve? As a molecule, this is what it might look like. The structure of the dye allows it to act like a molecular filter. Only certain wavelengths of light can pass through. Because silk or wool have electrical charges, and so does the dye, they stick to one another.

Reenactment of Perkin's
experiment, archival
photographs and footage
of labs, factories and
Germany

NARRATOR (MUSIC under):

Against his teacher's wishes, but with his family's help, Perkin dropped out of school to build his factory. A chemical synthesis like this had never gone into mass production before. The chemicals used in the lab, like aniline, were not available in bulk amounts. But if Perkin could do it, others could, too, and they did. Only one country had the right combination, the educational system and engineering skills needed by the new chemical industry -- Germany. Industry and academia were working closely with one another. Industry was paying for research and then hiring the new students out of the universities. (cont.)

NARRATOR cont:

For chemistry, it was the beginning of industrial research and development. The payoffs were immediate.

INTERVIEW: John K. Smith cont.

JOHN K. SMITH (SYNC):

Now, the way to find new dyes was get a large number of guys who were competently trained chemists, get them a laboratory, get them the major reagents, set them down and say, "Start making things."

Chemical solutions

NARRATOR (MUSIC under):

The path from coal tar to colorful dyes was long. There were many steps to the process. But each step produced new compounds and the experiments began building on themselves.

Archival footage of chemistry labs

JOHN K. SMITH (VO/SYNC):

You can't do a large number of experiments, because every experiment that you do, you have to start from scratch, essentially. (cont.)

JOHN K. SMITH cont:

But what happens as the Germans developed the dye industry, and they started making thousands of types of dyes, to make these dyes, you had to build up tens of thousands of intermediate compounds,

INTERVIEW: John K.
Smith cont.

you know, all produced on a, you know, rather reasonable scale. And what you have then is an enormous stable of things that you can use in experiments. And so the combinations, as the base broadens, the combinations just become infinite.

MONTAGE: Archival footage
and photographs, modern
chemistry labs, paints,
fibers, building blocks

NARRATOR (MUSIC and NAT
SOUND under):

From the dye industry's stockpiling of new chemicals, whole new industries emerged -- (SFX: Blast) explosives, fertilizers, and pharmaceuticals. From Perkin on, the connection between color and medicine was strong. But now scientists were able to analyze natural compounds and then synthesize them out of other compounds. (cont.)

NARRATOR cont:

Chemistry was becoming an applied science. In 1896, Bayer, a German dye company, manufactured aspirin out of coal tar. By World War I, the German chemical industry was dominant and was producing nearly all of the world's chemicals. It was the power of that industry which sustained Germany through the First World War. Even today, the leading manufacturers of chemicals are those same German companies with origins in the dye industry -- BASF, Hoechst, and Bayer. Now there are paints, plastics, pills, fibers and dyes of all colors, brighter colors, and colors for everyone.

RH in lab

ROALD HOFFMANN (SYNC):

The early years of chemistry were exciting ones. Not only new dyes, but flavors, pharmaceuticals, all kinds of useful molecules were readily synthesized, almost falling out of the pots of their makers. And 19th Century chemists were not only good at making pretty dyes to enliven the world, and to make Germany and England rich. They also turned color into a tool for advancing the science of chemistry itself. Early on it was noted that colors change, flowers fade, dyes bleach, or some change color when acid is added. (cont.)

ROALD HOFFMANN cont:

Chemists realized that these color changes could provide information under the very reactions in which they were interested. Color could be a tool to understand the molecular world within.

Swimming pool shots, color indicators, chemist working in lab

NARRATOR (NAT SOUND under):

How safe is the water? How much acid is in it? How much chlorine? These are chemistry questions. And when we devise tests to answer those questions, we turn to color. There are particular dyes we use to tell us about specific substances. They are called color indicators. Swimming pool test kits, home pregnancy kits, and diabetes tests all rely on color to show their results. Some common color indicators in the laboratory test for the amount of acid in solutions, as Don Showalter demonstrates.

DS in lab

DON SHOWALTER (SYNC):

In these three graduated cylinders, I have different dyes, each of them sensitive to different amounts of acid. Now, all of them are water solutions. I'm gonna add to them some dry ice, frozen carbon dioxide. (cont.)

DON SHOWALTER cont:

And as the dry ice is added, it will dissolve somewhat into the water and increase the acidity. It will become more acidic. Watch. We'll try the first one, which is thymol blue. A piece of dry ice. You see the bubbling that comes from there. Again, it has the dry ice, produces the carbon dioxide bubbles. Some of them dissolve in the water solution. And look what's happening. Oop! There's the color change. It went from that blue color to the yellow, because the acid increased, the acid content, the acidity of the solution. Let's try this one. Now, this one contains the dye phenolphthalein. It's a magenta color, isn't it? Very beautiful. I'm gonna add some solid carbon dioxide, dry ice, to it. Again, you see the bubbles of carbon dioxide. Some of those bubbles dissolve. And look at that. It's getting lighter, and lighter, and as the acidity increases, it becomes colorless. So this one changed from a magenta to the colorless solution. All right. Now, in this cylinder, there is a mixture of four dyes. Each of them now are sensitive to a different amount of acid. Now watch what happens in this one. We start out with that beautiful purple color. Oop! You see the blue coming in there? Because now, a different dye, sensitive to a different amount of acid. (cont.)

DON SHOWALTER cont:

There's the green, and there's the yellow. And finally, a red color. So you see the four different colors of the dyes, each of them changing because of the change in the acidity of the solution. So not only can we tell what is in a solution that contains an acid, but we can also tell how much acid is in there by the color change. So you can see that these dyes become a very powerful tool in chemistry for analyzing other chemicals.

GRAPHIC: Phenolphthalein structure

NARRATOR (MUSIC under):

If we could see a phenolphthalein molecule, it might look like this. Again, it is a small molecular filter allowing only magenta to pass through. But phenolphthalein is sensitive to acid. Changes in acidity cause the molecule to change shape, like this. It becomes three-dimensional, and its ability to filter light is diminished.

MONTAGE: Archival hospital footage, microscope stains, archival photographs of Ehrlich, microscope, microorganisms

NARRATOR (MUSIC under):

There's something else even more intriguing about dyes. At the turn of the century, sickness like tuberculosis, syphilis and the flu were attracting scientific attention. (cont.)

NARRATOR cont:

Doctors and biologists, searching for cures, began using the new dyes to stain their cell samples so they could see them more easily under the microscope. Paul Ehrlich, a young German doctor, noticed one dye which stained only certain cells, leaving others unaffected. He had an amazing insight. What if he could find a dye that would stain only bacteria, and what if he could attach a poison to that dye? Could he kill the microorganisms without poisoning the person? This was the beginning of chemotherapy research. In 1908, Ehrlich was awarded the Nobel prize. The first disease successfully fought with this technique was syphilis. But his dream of finding the magic bullet that would seek out and destroy all pathogens remains unfulfilled.

Lab work, microorganisms

NARRATOR

Biologists and histologists still employ similar procedures. Certain dyes can indicate the differences between cancerous cells and healthy ones. And there are further possibilities on the frontiers of biomedicine. Research in genetics, into DNA itself, uses color for mapping molecular architecture. Professor Jacqueline Barton, of Columbia University.

INTERVIEW: Dr. Jacqueline
Barton, Columbia University

DR. JACQUELINE BARTON (SYNC):
Color provides a very sensitive indicator
about what's going on, about the
chemical reaction that's forming, and
also we can use the color much as a
stain, as a handle to watch what's going
on.

Chemical solutions

NARRATOR (NAT SOUND under):
This is a compound Professor Barton
uses to stain DNA. The vial on the left
contains a solution of a special
ruthenium compound. It glows under
the ultraviolet light, but not much. The
vial on the right contains the same
compound and the same amount, but
DNA has been added. When the dye
molecule combines with the DNA, it has
a brighter glow.

INTERVIEW: Dr. Jacqueline
Barton cont.

DR. JACQUELINE BARTON (SYNC):
And the trisphenanthraline complex
combined to the DNA. Here's a
structure of the DNA. This is how we --

Dr. Barton working with
computer models

NARRATOR (NAT SOUND under):
Professor Barton and her colleagues are
designing propeller-shaped dye
molecules that bind in certain ways to
DNA.

Computer models

DR. JACQUELINE BARTON (VO):
And when it binds to the DNA, what we
think happens is that one of the blades of
the propeller is stacked in between the
steps, the rungs of the ladder of DNA.
We imagine that it's actually held quite
rigidly, and if it's held very rigidly, then
when it absorbs light, it will glow for a
longer period of time than when it was
just free in solution.

Computer models

NARRATOR:
But the Day-Glow dye combined to the
surface of the DNA, too, like this. And
when it does, it has a different glow.

INTERVIEW: Dr. Jacqueline
Barton cont.

DR. JACQUELINE BARTON (SYNC):
Telling us something about the local
DNA structure. So we can use them as a
reporter to tell us about the local
variations in that structure and how and
which they're binding to that structure
of DNA.

Computer models, laser beams

NARRATOR (NAT SOUND under):
But how can we use color to tell us
about the structure of DNA? The
ruthenium compound is excited by a
burst of laser light. This dye combined
in only two ways to DNA. It's the
surface features of the DNA molecule
that determine where it will bind. By
measuring the different glows, it is
hoped we can gain a more detailed
understanding of DNA.

INTERVIEW: Dr. Jacqueline
Barton cont.

DR. JACQUELINE BARTON (SYNC):
So for this experiment, what we're
gonna do is flash the sample, the
ruthenium DNA sample, in a very short
instant, and then watch the decay of the
glow from the sample from the
ruthenium down to the DNA complex as
a function of time. (cont.)

DR. JACQUELINE BARTON cont:

But since we're only gonna flash for an instant, you may not be able to see it.

Let's give it a try and see what we can see. There's the sample. Uh! There's one flash. Did you get that? It's gonna do it again. Okay. There it went again. Now let's see whether or not we can see what the computer is seeing in all this.

Okay. So now we can see this. Here's a spectrum after short periods of time, and every four billionths of a second, we can take that spectrum and watch the color and use that information to get dynamic information about how the complexes are binding to DNA. This becomes our probe, our way of looking in detail, and looking sensitively at the structure of DNA, doing it in ways that we just can't do it with our eyes.

MONTAGE: Computer models,
Perkin reenactment, program
graphics, greenhouses, plants,
solar panel experiments,
reflector, laser beams

NARRATOR (MUSIC under):

The next step is to design new Day-Glow dyes to bind to different places of DNA and eventually build a color map of the molecule of life. It has been a little over 125 years since William Henry Perkin first synthesized dye and started a whole new chemical industry. (cont.)

NARRATOR cont:

Since then, scientists have come to a broader understanding of molecules and their structure, which Perkin could only guess at. But as our knowledge of the molecular world grows, advanced applications, like staining DNA, are sure to follow. These experimental greenhouses have panels with fluorescent dyes. Plants need red or blue light to grow. The dyes on these panels take green light and turn it into red light. This helps the plants grow faster and be healthier. Even more exotic experiments are under way. Dyes might make solar energy more efficient. The dyes in these solar panels direct the sunlight to the edges, which are lined with solar cells. This means fewer cells are needed to generate electricity. Increased crop yields to feed an ever-expanding population, and electricity from the sun, and unraveling the mysteries of life itself, all with the chemistry of color.

RH in lab

ROALD HOFFMANN (SYNC):

We have seen the relationship between color and the world of chemistry. Color is not magic. In there are molecules absorbing and reflecting light. And chemistry is the science of those molecules. (cont.)

ROALD HOFFMANN cont:

Because it is a science, common sense, good hard facts, and logical thinking count, but so does intuition, and so does serendipity. The accidental discovery, a clever mind like that of William Henry Perkin to follow it up. Perkin was prepared for what he did by study with a great German chemist, August Wilhelm von Hoffman, no relation to me. And what Perkin did was not in a vacuum. Within a space of just a few years, several groups of German chemists were competing effectively with him. The German firms organized research teams to take basic knowledge into practical applications. For instance, to make a dye that could surpass natural indigo. The elements of the story, education, a chance discovery, its exploitation, collaboration, and competition, these are the hallmarks of modern chemistry. But most important, chemistry is a quest, a search for understanding of the molecular world around us. It's an exciting search. Think of Perkin when he first made that dye, and then, by changing the reagent, if he could get a different color. And you could feel Dr. Barton's excitement as she probed the ways to map out DNA with color. We will learn more about our molecular surroundings as we explore the world of chemistry.

Credits, Closing Montage, Closing Music

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